OPTIMIZATION OF THE SHORT RANGE WEAPONS CONTROL SYSTEM

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THESIS

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WEAPONS CONTROL SYSTEM

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June 1972

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ABSTRACT

This thesis deals with the evaluation of the performance of a strapped down air-to-air tracker for the Short Range Weapons Control System. The system was designed, built, and evaluated at the Naval Weapons Center. The subsystems of the tracker which contributed to the problem areas discovered by flight tests are described. An evaluation of the shortcomings of the tracking scan mode and the automatic gain control circuit is discussed and circuit modifications are proposed which include a collapsing square scan for target tracking and a variable width window discriminator.

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I. INTRODUCTION

This thesis deals with the performance/optimization of a strapped down air-to-air tracker for the Short Range Weapons Control System (SRWCS). The system which is essentially analog was designed, built, and evaluated for potential use as a tracker. A simplified block diagram of the tracker is shown in Fig. 1. The basic dynamic block diagram form of the system is shown in Fig. 2.

After conducting a number of flight tests, the following problem areas were defined. The acquisition system cannot maintain lock on a target when crossing the horizon, and rapid polarity reversals in background will cause loss of lock. [1]

This thesis will describe and then evaluate the performance of those subsystems which are contributing to the problem areas indicated [1], and then to propose the means by which circuit modifications or other improvements can be made to reduce, if not entirely eliminate, the system weaknesses. The overall intent is to present a means by which the basic system may be optimized in performance.

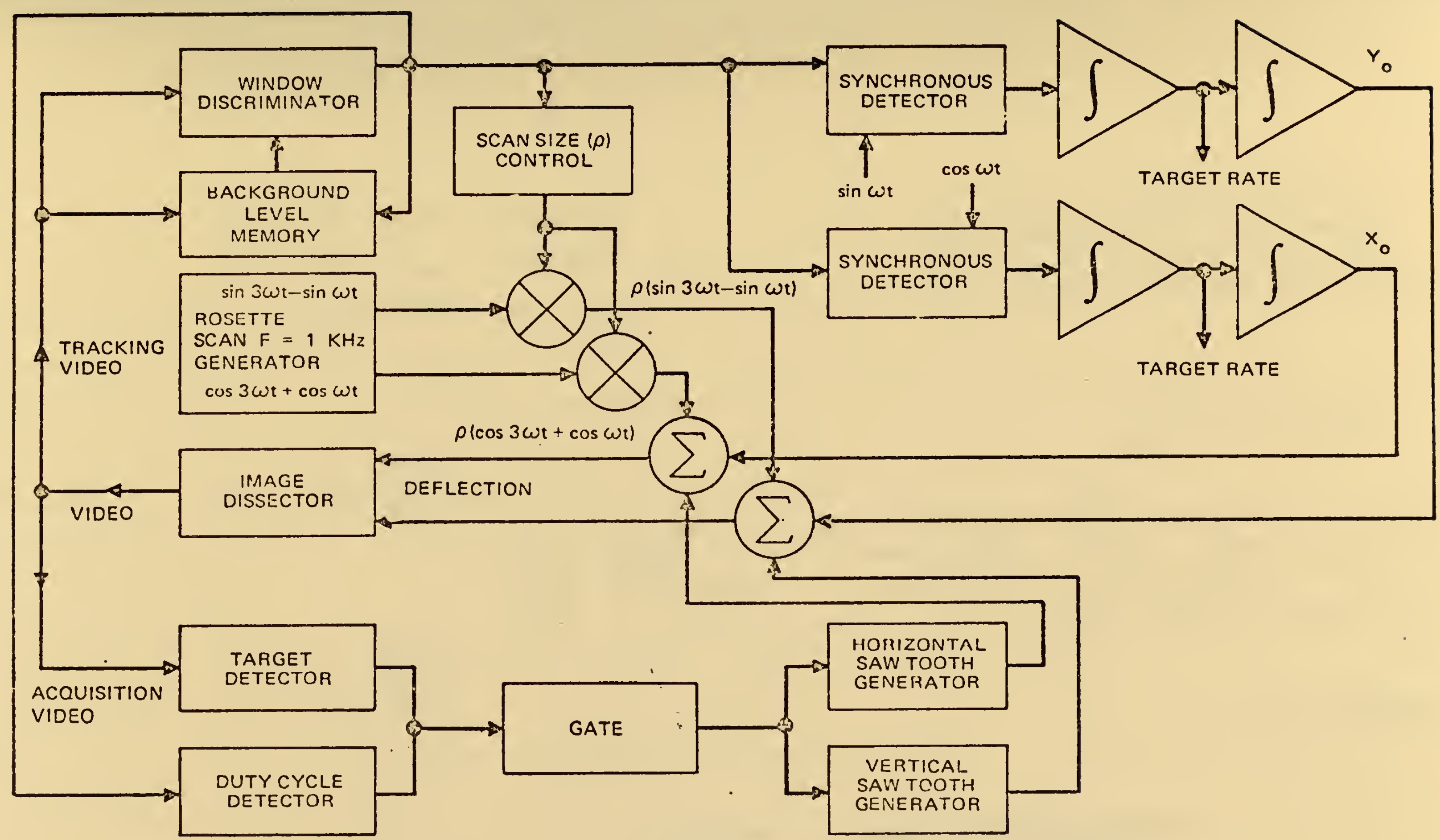


FIGURE 1. BLOCK DIAGRAM OF SRWCS TRACKER [1]

Gain of Error Processor

$$K = 0.625 \frac{V_{max} \text{ (volts)}}{\text{Target size (degrees)}}$$

B_x Actual target bearing
B_{cx} Computed target bearing
B_y Actual target elevation
B_{cy} Computed target elevation

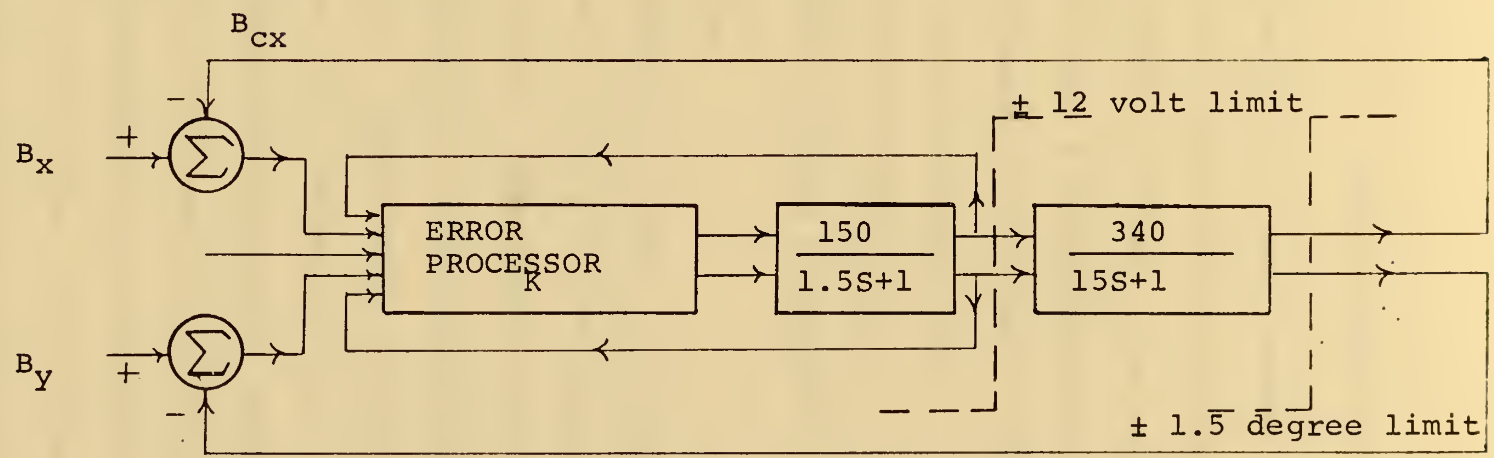


FIGURE 2. BASIC DYNAMIC BLOCK DIAGRAM OF SRWCS TRACKER

II. SYSTEM OPERATION

The image dissector has been deemed superior to a vidicon TV camera [1]. It is the opinion of the author that only by comparison of a specific vidicon tube with a specific image dissector tube can such a determination be made. The image dissector has the beneficial property that the photocathode is not subject to lag and raster burn. The tracker uses the concept of background referencing and a variable-tracking-gate unit. For a complete system description see [1].

A. IMAGE DISSECTOR

The image dissector as shown in simplified diagram form, Fig. 3, is an electronically deflectable photo-multiplier. From the forward face of the tube a photocathode emits electrons in proportion to the illumination from an optical image incident on it. This image is provided by a 50 mm lens. The image electrons are accelerated and focused into a plane containing a defining aperture which defines the resolution of the tube. Behind the aperture is an electron multiplier. Scanning of the photocathode is acheived by two magnetic fields at right angles to each other. The output of the image dissector is an analog voltage signal which is proportional to the light intensity of the image being scanned.

Historically, the image dissector has been described as "probably the only well known TV camera tube whose electro-optical conversion properties can be accurately predicted

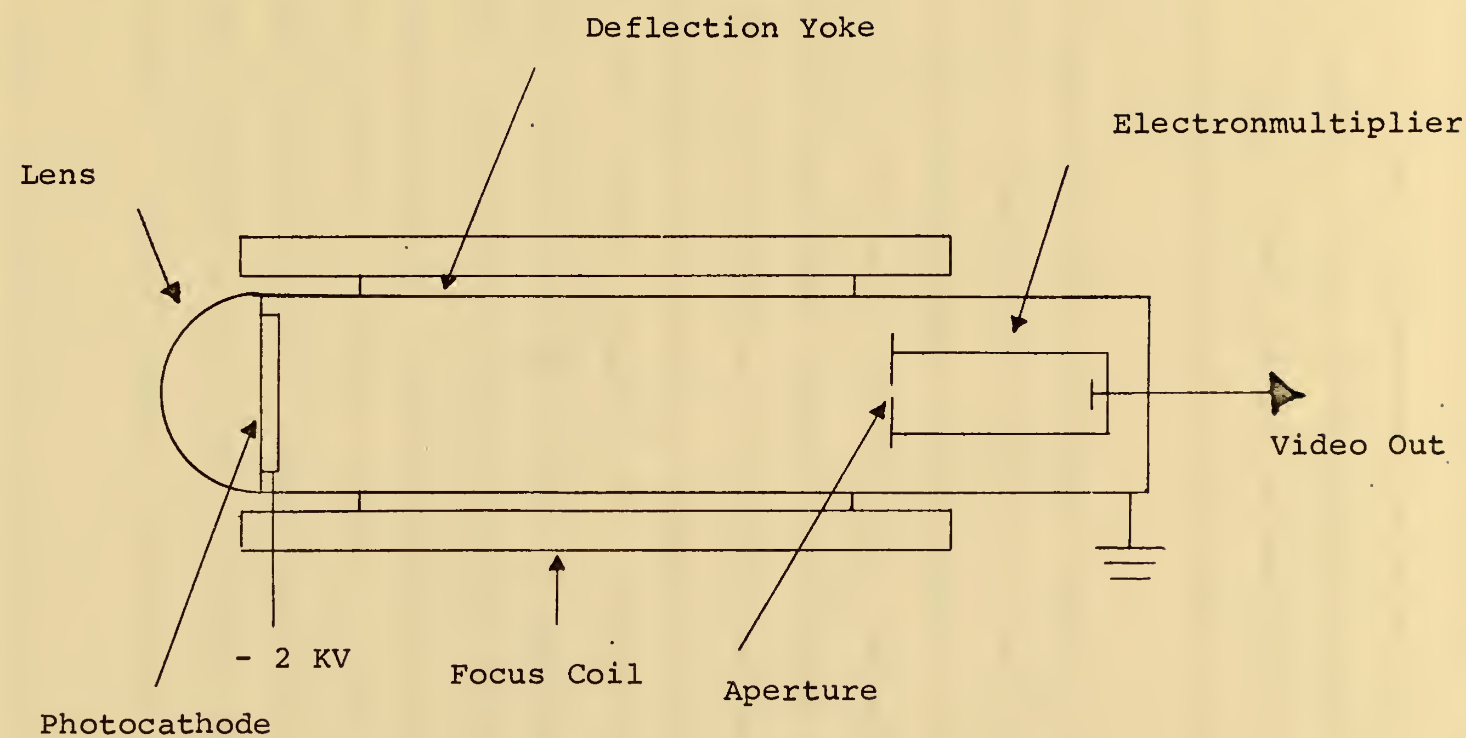


FIGURE 3. IMAGE DISSECTOR

without resorting to extensive emperical data" [2]. Essentially all known performance characteristics of photomultipliers pertain to the image dissector and at any image point the focusing properties can be described by a single parameter such as the variance of the Gaussian distribution [2].

In the acquisition mode of system operation the image dissector uses a standard horizontal TV type raster scan to sweep the center three-degree field of view. The presence of a target is indicated by the threshold detection of the differentiated video output signal of the image dissector. Detection of a target switches the seeker to the tracking mode which consists of a spinning rosette scan centered about the target. The maximum diameter of this scan is one and a half degrees to which the scan blooms at the commencement of tracking. A duty cycle detector circuit thereafter controls the scan size of a rosette pattern to maintain a ratio of forty percent on-target to sixty percent off-target. This provides for both target tracking and background referencing. When in the tracking mode, the target will be tracked anywhere within the thirty degree field of view of the seeker's 50 mm lens.

The tracker's intended use is for air-to-air encounters within the range of from one thousand to five thousand feet. If is it assumed that in the majority of encounters the target will have a tail-on aspect, then a target diameter of twenty five feet represents a reasonable target size. At the

maximum range considered, this target will subtend approximately three tenths of a degree and at the minimum range almost one and a half degrees which is a limiting factor for minimum tracking range. The effective target size is directly proportional to the angle it subtends. The present lens system is designed to detect targets at the maximum range and only by utilization of a different lens system would an increased target range capability be provided. For a more complete description of the image dissector see [2, 3].

In order to study the operation of the image dissector under quasi-laboratory conditions, the author modified the seeker circuits in order to observe the output voltage of the image dissector when in a continuous tracking mode. The acquisition mode was disabled and the rosette scan enabled continuously. A series of oscilloscope pictures were taken of the image dissector amplified output voltage waveform at the output of operational amplifier (A 101), as shown in Fig. 4, while the seeker was pointed at a target. This video signal is used for all tracking circuit decisions.

The target used was a six foot square piece of plywood placed upright outside the laboratory at the Naval Weapons Center where the seeker was built. The seeker rested horizontally on a workbench and was pointed through an open door. The target was painted half white and half black with a vertical boundary. The target was placed approximately twenty feet from the seeker's lens so that the tracker could be pointed such that the target was totally within the seeker's

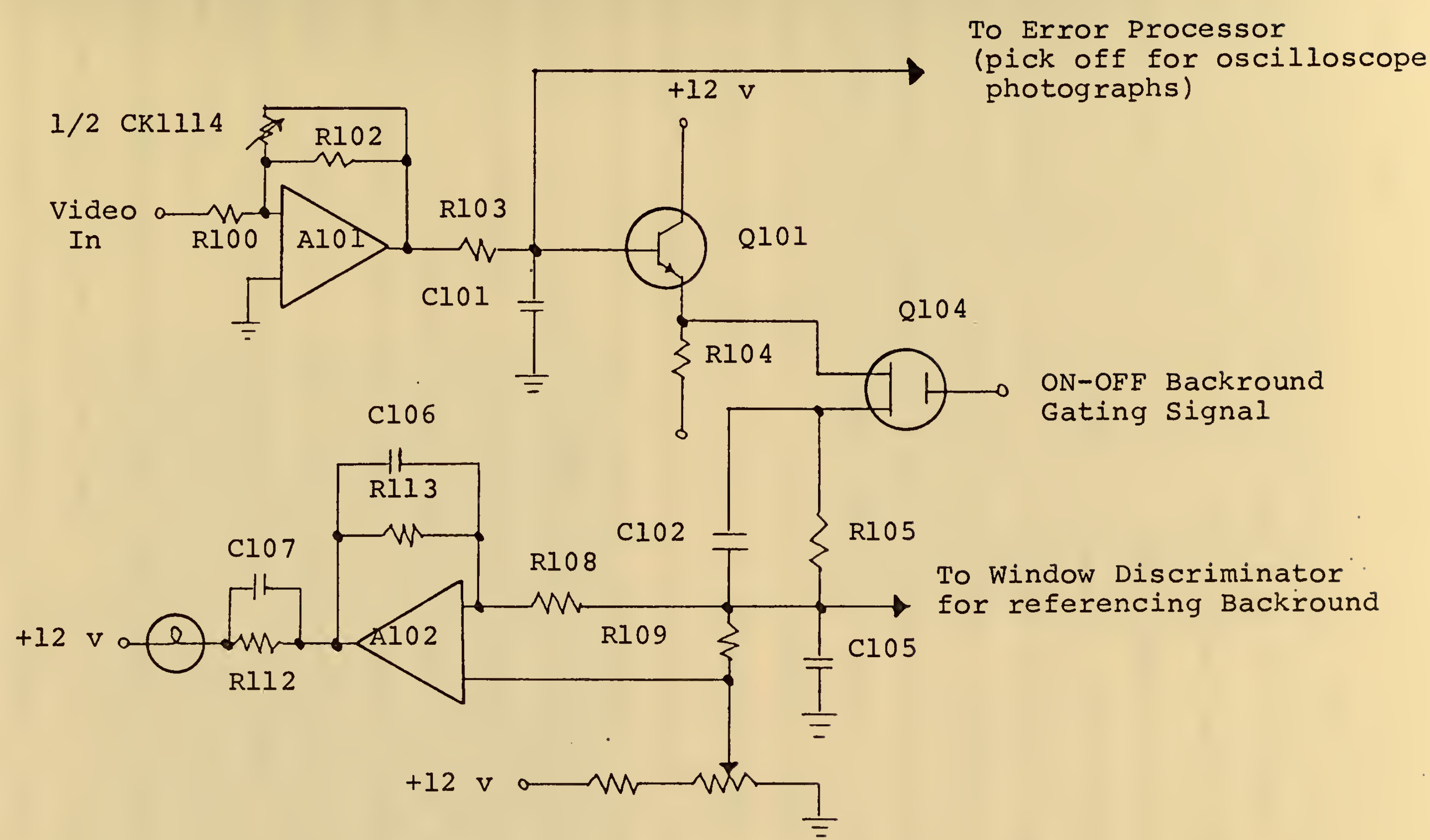
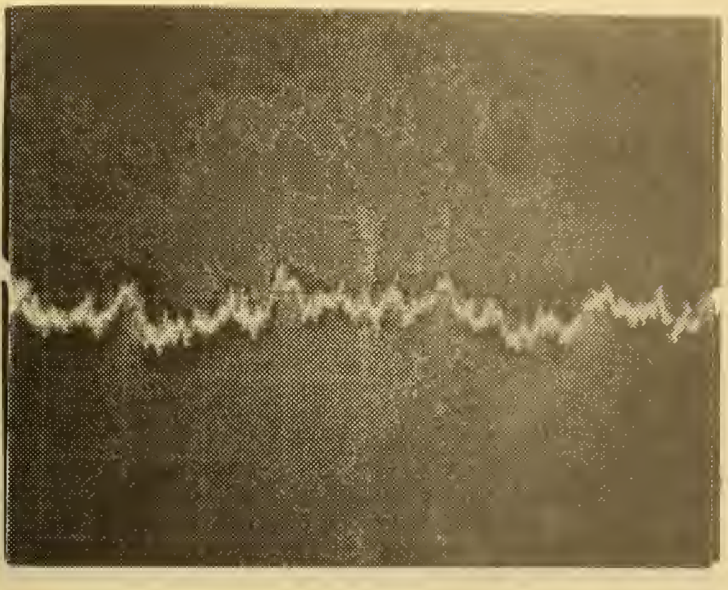


FIGURE 4. TRACKER AGC SYSTEM [1]

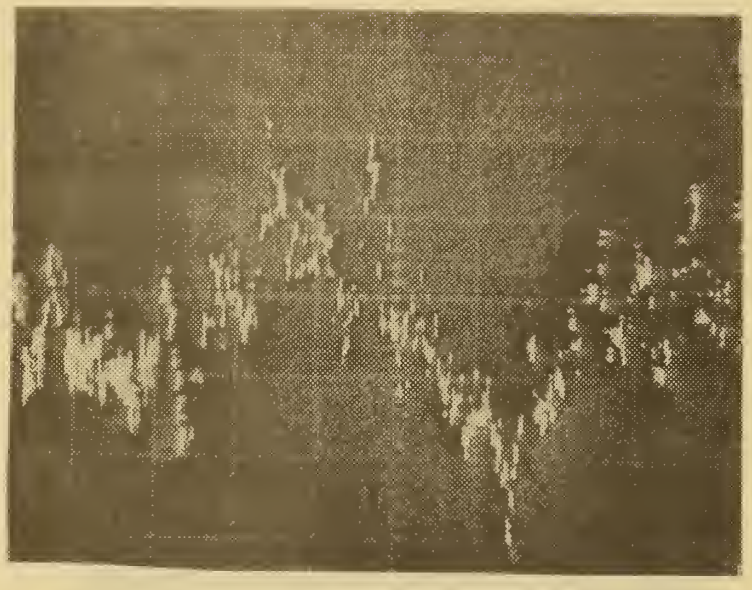
field of view.

The voltage waveforms observed are shown in Fig. 5. Figure 5 a. is the waveform seen when the target is only the white portion of the board. The maximum amplitude variation peak-to-peak in the signal is about twelve millivolts. Figure 5 b. shows the effect caused by the increased noise in the system as a result of changing the lens stop from F 2.8 to F 5.6. The maximum amplitude variation has increased approximately five times above the previous condition. Figure 5 c. shows the video signal when the target is the boundary between black and white. Since the seeker's field of view was swinging from white toward the boundary, the reference voltage was obtained from the white portion of the target. The large negative spikes indicate scanning of the black portion of the target. Since the error detector of the system was disabled, no problem was incurred by the error detector of the system attempting to adjust the tracking axis of the system. Note that there are no positive spikes generated. Figure 5 d. shows the unusual signal in which both positive and negative spikes occur. The seeker, pointed at the black section of the board, was viewing both the white of the other side of the board and also the real background to the right of the target board. This was a laboratory situation which would represent an extremely small number of the target situations in which the seeker would be called upon to function.



a. WHITE BACKGROUND

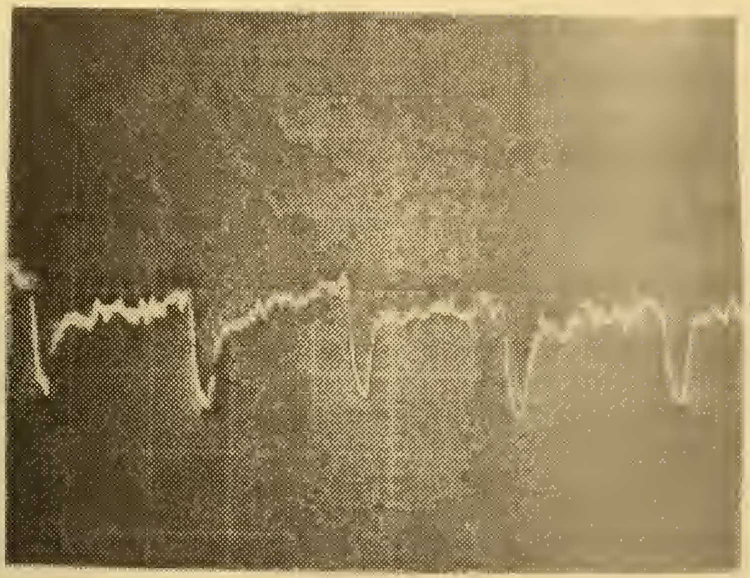
LENS F 2.8



b. WHITE BACKGROUND

LENS F 5.6

FIGURE 5. IMAGE DISSECTOR VIDEO VOLTAGE AMPLITUDE VERSUS TIME



c. WHITE BACKGROUND
WITH BLACK TARGET
LENS F 2.8

d. BLACK BACKGROUND WITH
DUO-VOLTAGE TARGET
LEVELS LENS F 2.8

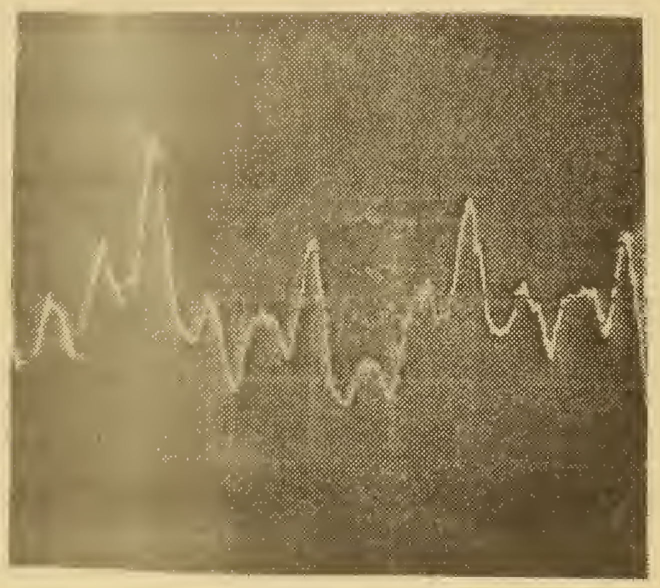


FIGURE 5. (Cont.) IMAGE DISSECTOR VIDEO VOLTAGE AMPLITUDE VERSUS TIME

B. ROSETTE SCAN - TRACKING MODE

The tracking mode utilizes a four-leaf rotating rosette scan. The leaf pattern is generated at 1 KHz and the leaf rotates at 50 Hz. The rosette generator consists of two oscillators (1 KHz and 3 KHz) as shown in block diagram form in Fig. 6. When the oscillators are not synchronized, a spinning rosette scan is generated. However, by synchronizing the two oscillators a fixed (non-spinning) rosette scan results.

During the design of the seeker, computer studies were made to evaluate the tracking performance of the closed loop system for both the spinning and the fixed rosette scans [4]. The tracking loop evaluated was that shown in Fig. 2. The computer studies revealed that there is a significant improvement in tracking accuracy when the spinning pattern is used instead of the fixed pattern [4].

C. AUTOMATIC GAIN CONTROL (AGC)

The AGC subsystem operates differently for each of the two seeker modes. Both modes utilize video amplified circuits. In the acquisition mode a variable feedback resistance controls the gain. In normal sunlight (5,000 - 10,000 foot-candles) the image dissector will cause at least two hundred millivolts to be applied to the target detector. As the scene illumination decreases, the system gain increases to maintain the video signal constant. The responses of the AGC loop will detect a change in illumination between two vertical line scans [1].

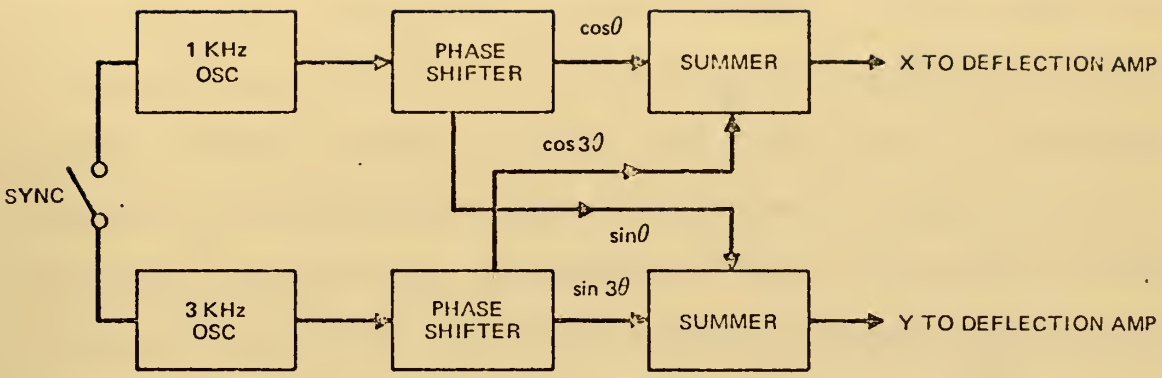


FIGURE 6. BLOCK DIAGRAM OF ROSETTE GENERATOR [1]

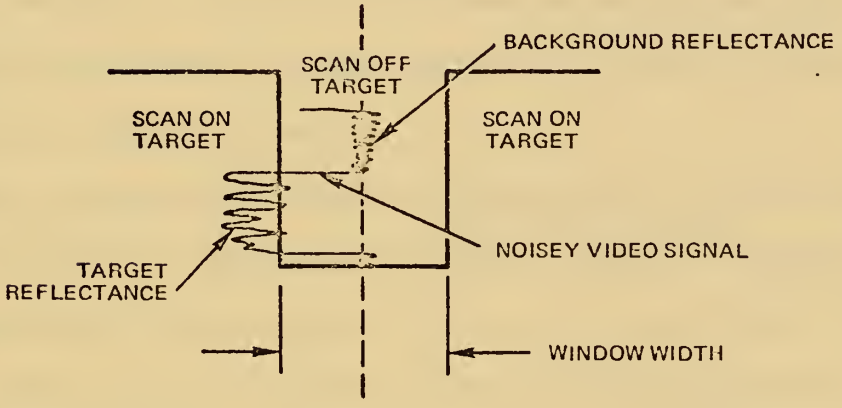


FIGURE 7. WINDOW DISCRIMINATOR CHARACTERISTICS [1]

In the tracking mode the AGC functions somewhat differently. The image dissector raw video is amplified by an operational amplifier as shown in Fig. 4. The gain of this amplifier (A 101) is controlled by the parallel combination of two resistors (R 102 and 1/2CK 1114). The second element is a "rayistor" whose resistance is controlled by the light from a small incandescent bulb. The bulb's resistance is controlled by varying the DC potential across it. The brightness of this bulb is controlled by the output of another operational amplifier (A 102). One of its inputs is the stored reference voltage obtained by charging capacitor (C 105) whenever the rosette scan is off-target. As shown in Fig. 4, the switching action of FET (Q 104) gates the off-target condition. The combination of elements C 102, C 105, and R 105 average the sampled video background. The circuit time constant is thirty milliseconds which has been experimentally determined to be satisfactory for tracking aircraft with this seeker system [1].

This system can be easily modified to utilize sampled target video to reference the AGC circuit. However, since no particular advantage is to be gained and due to the probable generation of tracking errors from variations in the target video signal resulting from glint, the target video voltage level is not being sampled and stored.

D. WINDOW DISCRIMINATOR

The window discriminator is a vital portion of the tracker's circuits. It is the only analog-to-digital converter in the system and it provides the means for generating the gating signals which indicate ON-OFF target conditions. The background reference voltage, which controls the AGC, also controls the video amplitude so that it remains centered within the discriminator window. This circuit is so called because its transfer characteristic may be viewed as a window, Fig. 7. The discriminator is built around two voltage comparators (A 201 and A 202), Fig. 8. The video signal from the image dissector is compared with the upper and lower limits of the thresholds as shown in Fig. 7. The output of the discriminator is a logical zero when the video signal is inside the window and a logical one otherwise.

The width of the discriminator transfer function is fixed. The width was set under laboratory conditions to permit a false alarm rate of twenty percent. The assumption was made that the noise distribution is Gaussian and thus a minimum signal-noise ratio determined. The effect of Gaussian noise is shown in Fig. 9.

E. ERROR DETECTOR

Target tracking is performed and maneuvers detected as indicated by the closed loop system shown in Fig. 2. The signals Bx and By are generated by the error detector. The squarewave output form from S and T, Fig. 8, are used to gate

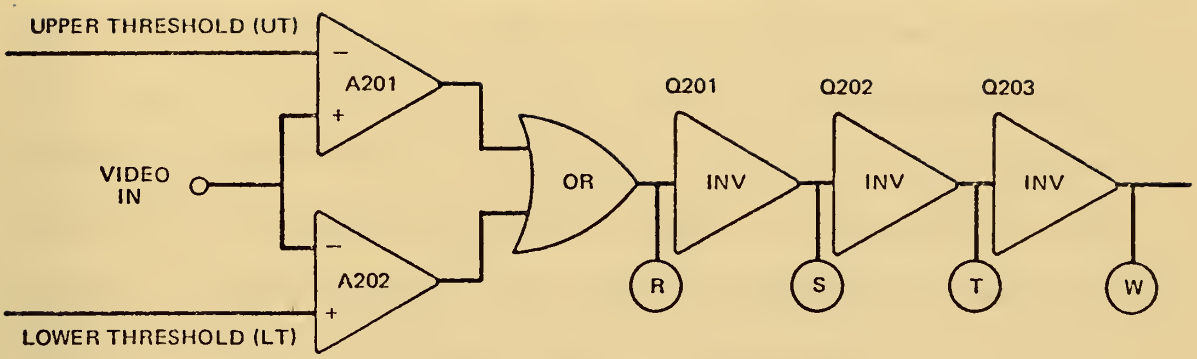


FIGURE 8. WINDOW DISCRIMINATOR [1]

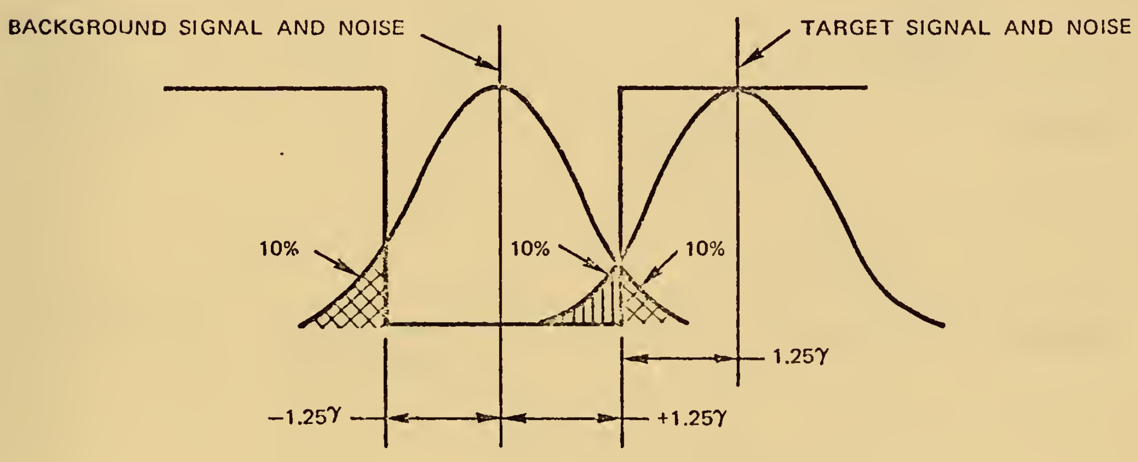


FIGURE 9. NOISE DISTRIBUTION [1]

two FETs. These two signals are used to gate a signal from the 1 KHz oscillator of the rosette generator and the same 1 KHz signal with a ninety degree phase change. These sine and cosine signals are thus directly correlated to the ON-OFF target condition. The sine wave is a maximum when the rosette is OFF target in azimuth. Similarly, the cosine waveform is a maximum when OFF target in elevation. The result is shown in Fig. 10. When the average value of the signal is zero, no error signal is generated.

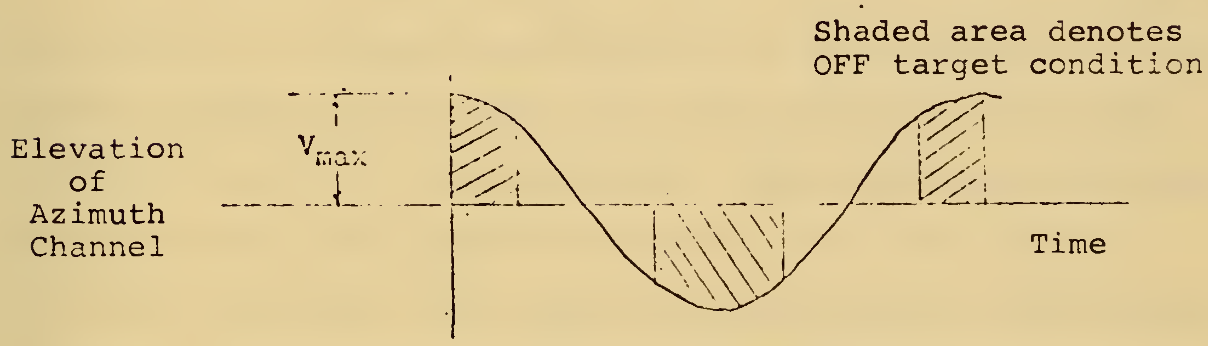


FIGURE 10. ERROR PROCESSOR OUTPUT SIGNAL FOR ON TARGET SITUATION

III. EVALUATION AND ANALYSIS OF SYSTEM DEFICIENCIES

There are two areas in which the present system can be optimized or improved upon. The first area to be investigated was to insure maximum utilization of raw video from the image dissector. The second area was to insure that all practical logical decisions were made and that use was made of the maximum correlation between logical decisions and raw video. Since the video signal information is only in the form of unpredictable amplitude variation, the statistical techniques such as matched filters are not appropriate.

A. TRACKING SCAN MODE

The present spinning rosette scan does not permit adequate utilization of information available by the correlation of the image dissector video signal with the position of the photocathode from which it was received. The only scan correlation now utilized in the system is that for the error detector circuit to maintain the rosette scan centered on a maneuvering target. A major shortcoming of the system is that it is not able to maintain lock when the target crosses the horizon. This is due to this lack of correlation. The second shortcoming, the inability to maintain lock when there are rapid polarity reversals, might also be reduced by improved correlation between scan and video amplitude.

If it were feasible to determine when the video signal was coming from the tips of the spinning rosette, as shown

in Fig. 11 b, this indication could be correlated with the window discriminator ON-OFF target indication. It would then be possible to identify both major changes in background video amplitude, which presently confuse the window discriminator logic decisions by providing a false background reference voltage, and also provide a means for detecting when the target has crossed the horizon. By detecting an abrupt change in magnitude of background video voltage level as sensed on each of the rosette tips, the tracker would be given the means to stay locked on target which does not now occur.

Since the scan size control circuit is designed to maintain the rosette scan with sixty percent of the scan off-target, it is desirable to sense the measurement of the final ten percent of the rosette tip, which should never scan the target being tracked. This separation of about thirty percent of the rosette leaf between target and tip would essentially eliminate false alarm signals other than those noise signals inherent in the system.

With tip correlation logic a series of encounters as viewed by the tracker are shown in Fig. 11 b and c. The uniform background situation is that of Fig. 11 a. As the target approaches the horizon, it would be sensed by the tip which is shown dipped below the horizon in Fig. 11 b. With tip logic the tracker would not break lock and track the horizon as it now is likely to do. Also an erroneous background voltage level would not be sampled and generate an incorrect background level. Once the target crosses the

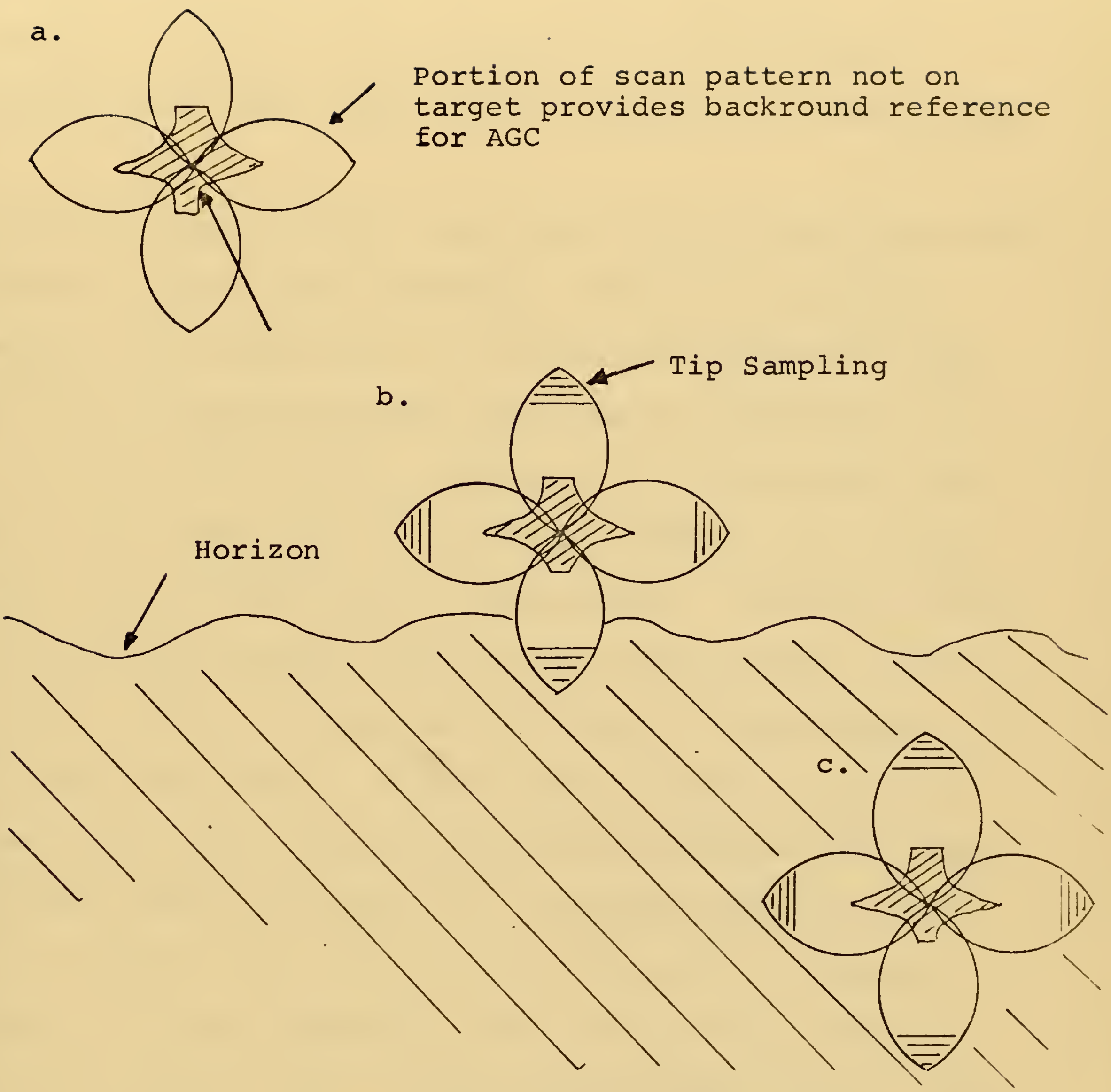


FIGURE 11. ROSETTE TRACKING SCAN CENTERED ON TARGET.

a. PRESENT SCAN WITH UNIFORM BACKROUND.

b. PROPOSED TIP SAMPLING WITH ROSETTE AT HORIZON.

c. PROPOSED TIP SAMPLING AFTER TARGET HAS CROSSED HORIZON.

horizon, tip logic would provide the means by which the requirement to acquire a new background video reference voltage is recognized. This is the situation as shown in Fig. 11 c.

Due to the phase shifter operation of the rosette generator, the spinning rosette scan presents a difficult problem in implementing tip correlation. The amplitude voltage of the rosette leaf is not measureable when the two oscillators in Fig. 6 are not synchronized. However, by synchronizing the 1 KHz and 3 KHz oscillators, the fixed rosette scan is generated and its leaf amplitude is measureable. Since the fixed rosette has less tracking accuracy than the spinning rosette, the rosette scan is an unacceptable means of implementing "tip" logic correlation. Another type of scan is required in order to be able to perform the desired logical decisions.

With the advent of monolithic integrated circuits (IC), it is now possible in a single 16-pin standard IC package to obtain a waveform generator which can provide outputs in the form of a square wave, triangle wave, ramp function, and sine wave all essentially from the same package at the same time with a frequency range far exceeding the less than 5 KHz requirement for the image dissector tracker system. The monolithic waveform generator permits the utilization of linear waveforms without the limitation of having to use discrete (nonintegrated) circuits [5].

When using monolithic waveform generators it is desirable to determine if a linear type of tracking scan can adequately replace the spinning rosette, have similar tracking accuracy, and also provide measurement of "tip-like" indication. There is one such scan which is not difficult to implement. This is a scan called a "collapsing square", This scan is obtained by using two unsynchronized triangle waveforms of the same frequency to replace the X and Y axis rosette scan inputs to the image dissector deflection amplifiers. The unsynchronized waveforms cause a signal pattern which is a square centered about the target center, which alternately collapses about the diagonals of the square.

An experimental setup of this concept was evaluated using only laboratory equipment as shown in Fig. 12 a. The waveform which was generated is shown in Fig. 12 b. It is visualized that this scan would operate at 1 KHz which is now used for the rosette scan. It was noted that the area coverage of this pattern is more uniform than the rosette scan which covers the center of the pattern more frequently than it covers the leaf tips. However, the loss of the center scan coverage is not a significant information loss. The number of target edges cut normally by the scan will determine its effectiveness. The scan size can be varied and its center moved to track a target.

In order to implement the collapsing scan, consideration must be given to the means of error detection. At present, the system utilizes the signal from the 1 KHz oscillator as

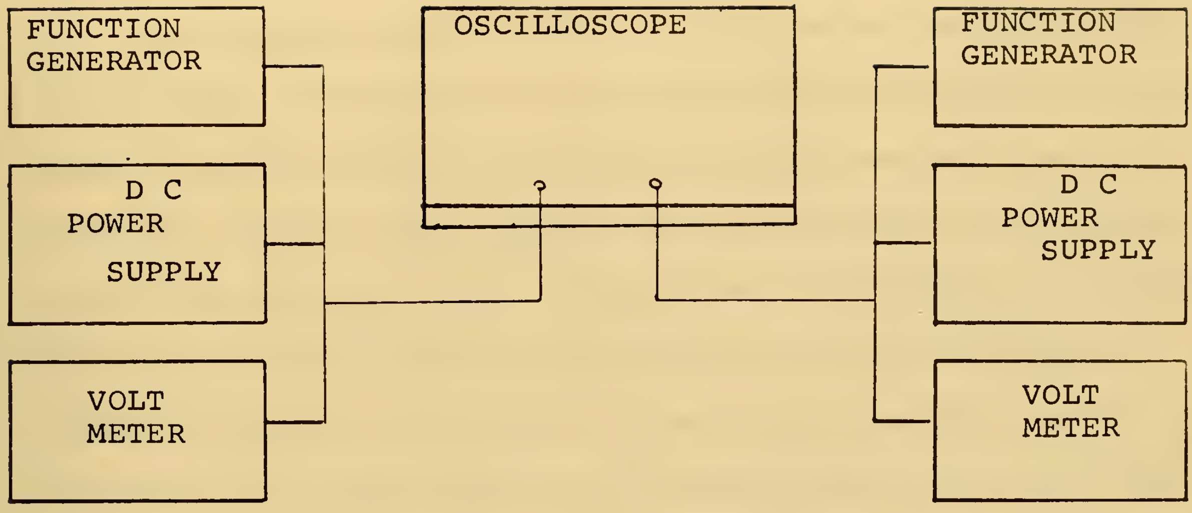


FIGURE 12 a. LABORATORY SETUP FOR
COLLAPSING SQUARE SCAN EVALUATION

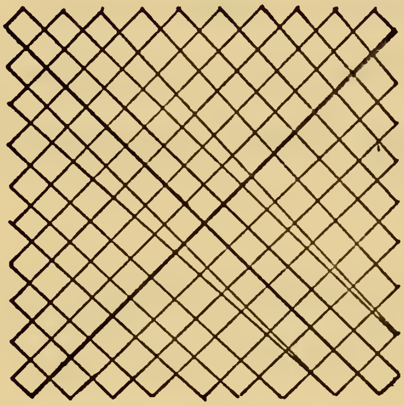


FIGURE 12 b. LABORATORY GENERATED
WAVEFORM OF COLLAPSING SQUARE SCAN

a means of error signal generation. By the use of an active filter with the square wave output of the monolithic waveform generator as its input as 1 KHz sine wave can be obtained and is thus available for use in the same manner as the rosette scan system. The primary advantage of the collapsing square scan system is the ease at which the maximum amplitude of both the X and Y axis signals can be monitored and used for logical decisions. This information is available by threshold detection of the double differentiated triangle waveform. Also, the maximum amplitude of the square pattern can be controlled in the same manner as now provided by the scan size control circuit.

By replacing the rosette generator and its phase controls with the collapsing square generator, nine transistors and several dozen associated components can be replaced with two 16-pin IC packages, two operational amplifiers for use as active filters, and less than a dozen associated components. This is a space, weight and cost savings in addition to gaining the additional monitoring capability of the scan pattern.

B. AUTOMATIC GAIN CONTROL CIRCUIT IMPROVEMENTS

The width of the fixed window discriminator was determined under laboratory conditions prior to any flight tests. The width was set for a stated false alarm rate of twenty percent as shown in Fig. 9. However, this false alarm rate is somewhat misleading especially when considering a typical signal

waveform such as that of the black and white target boundary in Fig. 5 c. In this figure, the target spikes are only in one direction. Therefore the false alarm rate for a single target encounter as this example shows is actually only ten percent. This is a relatively low false alarm rate which may, in fact, be more conservative that the system can tolerate and still provide satisfactory tracking performance. Also, in a real world condition, such as when a target is tracked through the horizon interface, the background can become very nonuniform and a video signal similar to Fig. 5 d is not unlikely. With such an amplitude waveform, target identification with the present system becomes much more difficult and the false alarm rate as presented in [1] losses its meaning. Thus it is desirable to consider the implications of changing the window width..

By implementing a window of variable width, the real life dynamics of the tracking problem can be handled over a wider range of environmental conditions. In order to accomplish this change both background video and target video voltage references are required. A comparison of the difference between these two levels, within the limits of a preset maximum and minimum, would provide both the amount and the direction of window width change as a voltage (delta V). Figures 13 and 14 show basically how this circuit modification could be implemented. The signal to gate FET (QX 104) is available in the present system by using the output of an inverter as shown in Fig. 8.

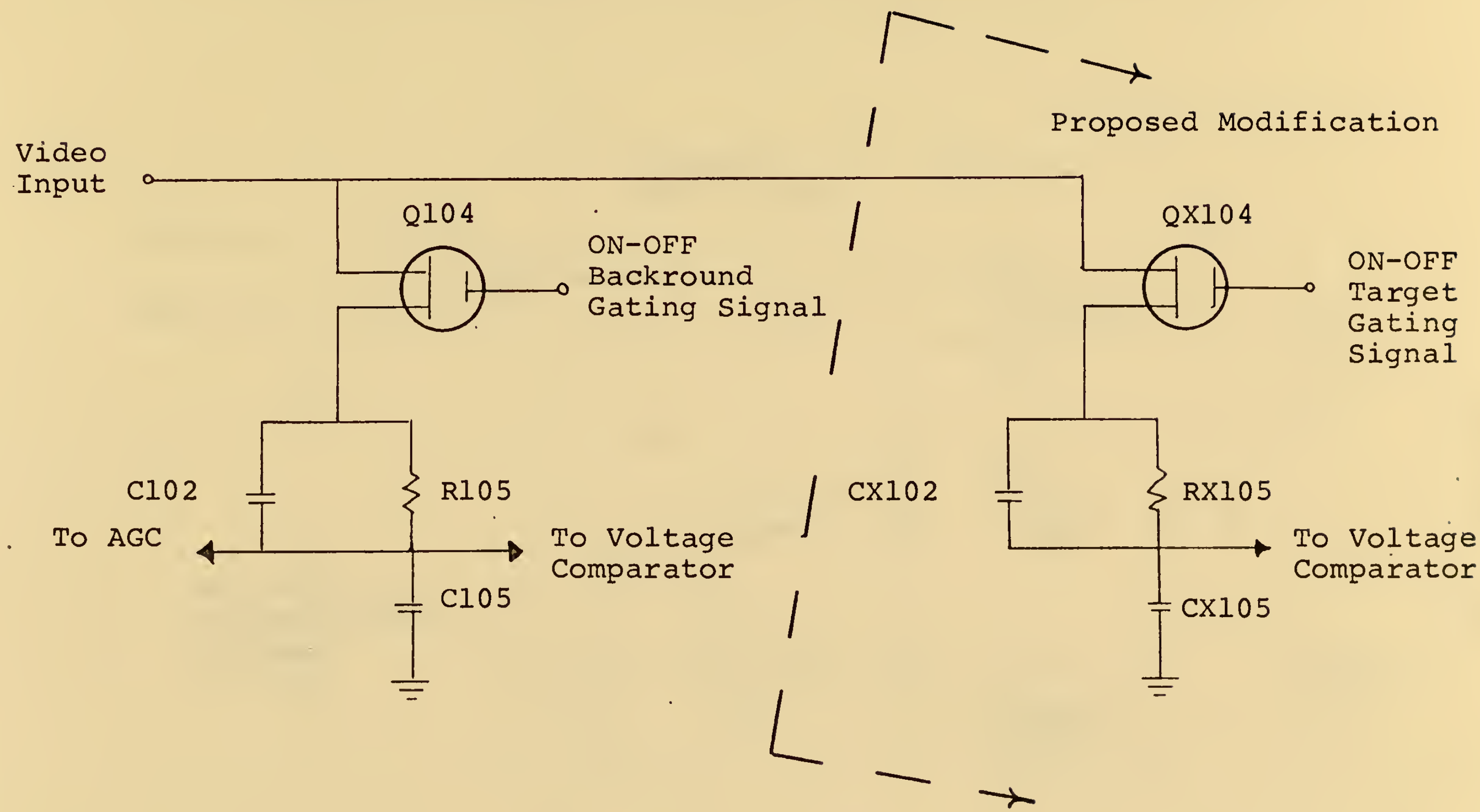


FIGURE 13. PROPOSED VOLTAGE REFERENCE CIRCUIT MODIFICATION TO AGC TRACKING SUBSYSTEM

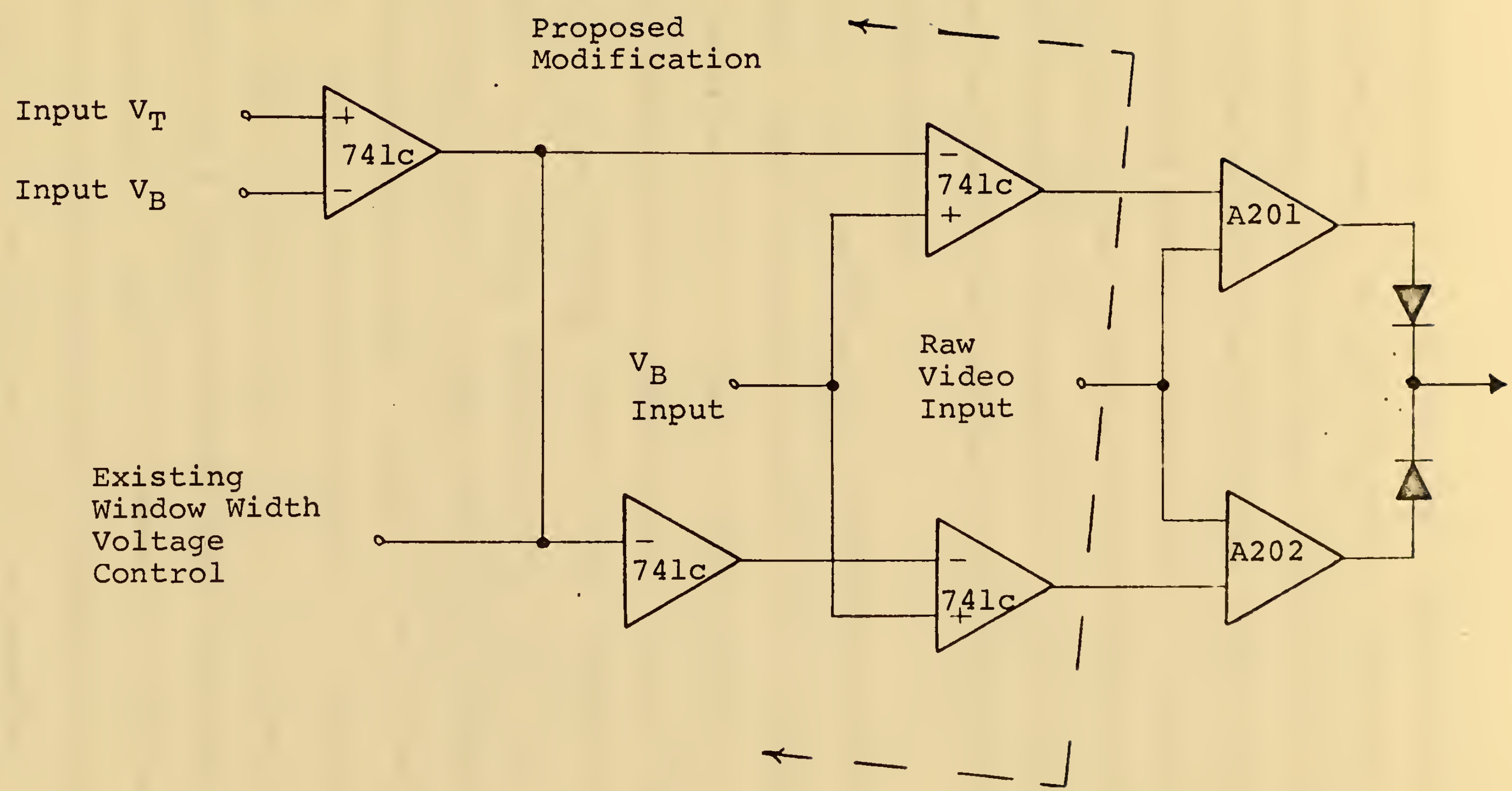


FIGURE 14. PROPOSED WINDOW DISCRIMINATOR VARIABLE VOLTAGE CONTROL CIRCUIT

Implementation of the variable window width permits the tracking of targets under variable lighting conditions. The present system requires that the lens F stop be set prior to each flight for the anticipated background light level. Background conditions produce varying levels of noise and large amplitude variations would be better handled by the variable width as would be the condition in which the contrast between target and background dropped below that now prescribed for fixed window detection.

In addition to the modification of the AGC circuits to include a target video reference circuit, use can be made of the logical decision that a target is sensed while a "tip" of off-target scanning edge is sampling the photocathode. This logical decision could be used to gate another FET as shown in concept in a signal flow form, Fig. 15. This would provide a sampled video for a third reference voltage for the reversed background polarity signal situation which occurs as the target crosses the horizon interface. This reference voltage would then be used to rebias the AGC system so that target tracking could continue through this interface.

Due to the system's inability to maintain lock during a change in the AGC bias resulting from a reference shift, a "coast" or memory mode would have to be implemented. Also, whenever the limits of the difference voltage were reached, the "coast" mode would be implemented. This mode would, for a preset period of time, lock out tracking error signals to the integrator circuits and thus maintain the current tracking

solution being generated. Although the seeker may ultimately loose lock on the target, these changes provide a means to keep lock under more stringent conditions than now exist. There are certain environmental conditions similar to those which generated the video signal of Fig. 5 d in which lock will be lost regardless of how the system is implemented. The system is limited by its overall ability to distinguish the difference between target and background video. In some situations, target-to-background contrast is at such a low level that detection and tracking is not feasible.

IV. SUMMARY OF RESULTS

Only by the maximum utilization of the correlation between logical decisions and video scanning can an image dissector be effectively used as an air-to-air tracker. The present system only makes a small effort in this direction. It is limited by its sinusoidal type tracking scan, fixed window discriminator width, and its lack of measurement of all voltage reference information which is required to adequately track targets under daylight conditions and varying background conditions. System modifications should be made to provide for the processing of the raw video signal as shown in Fig. 15.

By this initial processing of the raw video, utilizing the collapsing square scan, the means exists by which a more comprehensive correlation of information can take place. The logical decisions of ON-OFF target and ON-OFF scan boundary edges provides the ability to solve the horizon interface problem as well as provide a means for improved target tracking under a wider variety of daylight conditions than presently exists.

The additional logic capability can be implemented as shown in Fig. 16 to cause a change in the AGC reference voltage after the target has crossed the horizon. Unless the target maneuvers precisely as the reference transfer takes place, lock-on will be maintained throughout the

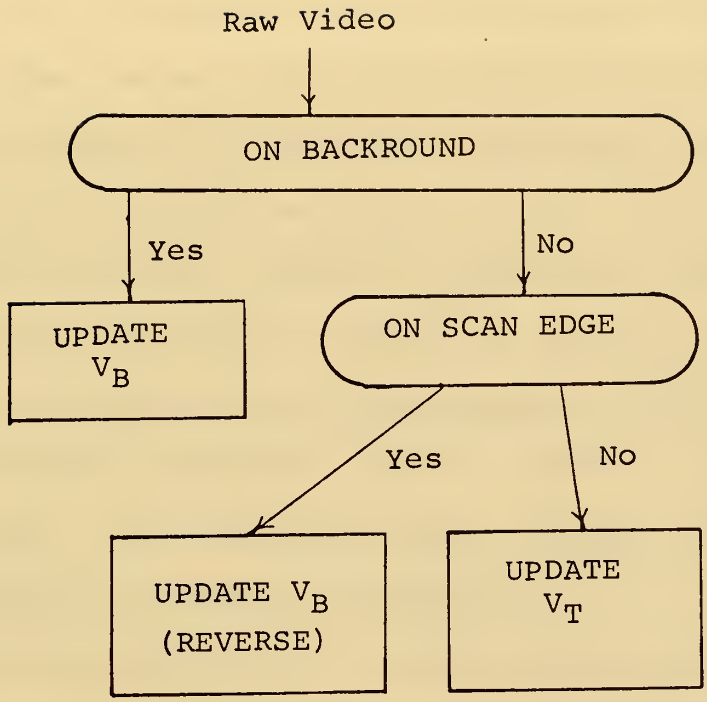


FIGURE 15. PROPOSED SIGNAL FLOW FOR IMAGE DISSECTOR VIDEO

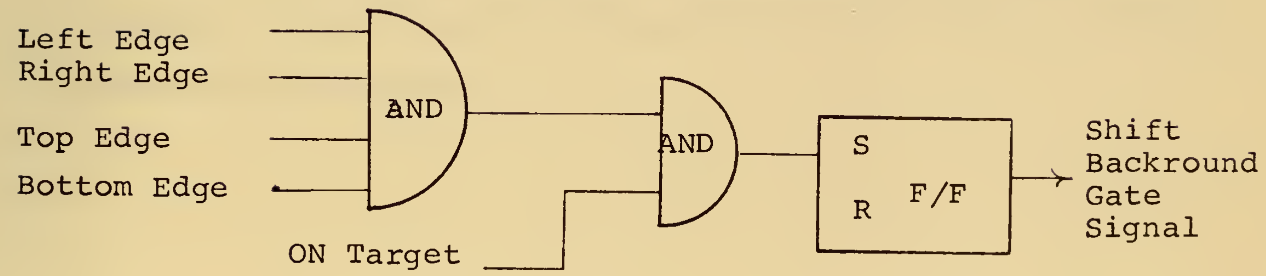


FIGURE 16. PROPOSED LOGIC FOR SHIFTING BACKGROUND VOLTAGE REFERENCE

transition and afterwards even with a different background providing the background polarity reversals are not too severe. This can be accurately determined only under flight conditions although a laboratory target and background simulation will provide some indication of the tracking effectiveness under this condition. Figure 16 shows the effect of logical decisions and the digital format now available to the circuit designer. Although voltage amplitudes are not quantized but rather threshold detected, the net result is to convert an analog signal into a discrete logic signal which is readily handled utilizing digital techniques.

The overall success of the recommended improvements as indicated in this thesis depends on the ability of the collapsing square wave to replace the spinning rosette. It is essential, therefore, that a thorough investigation be undertaken to determine all of the properties of this new scan and whether or not any shortcomings exist. Both laboratory and flight tests will be required to fully analyze this innovation. It is therefore recommneded that all of the changes and modifications proposed in this thesis be implemented for evaluation.

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13. ABSTRACT

This thesis deals with the evaluation of the performance of a strapped down air-to-air tracker for the Short Range Weapons Control System. The system was designed, built, and evaluated at the Naval Weapons Center. The subsystems of the tracker which contributed to the problem areas discovered by flight tests are described. An evaluation of the shortcomings of the tracking scan mode and the automatic gain control circuit is discussed and circuit modifications are proposed which include a collapsing square scan for target tracking and a variable width window discriminator.

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